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Design of transfer lines for INDUS-I

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Abstract : For synchrotron radiation source INDUS-I, electron beam from an injector microtron is to be transported to the booster synchrotron and from the synchrotron after acceleration to the storage ring INDUS-I with proper matching of beam parameters. Design of the two transfer lines is discussed from the beam dynamics considerations.

Keywords : Beam transport, booster, storage ring, matching.

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1. Introduction

Beam transfer line transports the beam from one accelerator to another accelerator. It should be designed in such a way that minimum loss of particles takes place during the transport process. It is achieved by focussing the beam by using the proper combination of quadrupole lenses. In order to improve the efficiency of injection into the receiving accelerator, phase space parameters of the beam are adjusted with those of the accelerator at the point of injection by using suitable arrangements and strengths of quadrupoles. In addition, it is also used to regulate the dispersion function and its derivative at the injection point to meet the requirements of the injection process. Provisions can also be made in the transfer line for reducing the momentum spread of the injector beam if required and producing single bunch necessary for the single bunch operation of the storage ring.

Two transfer lines are designed. Transfer line 1 transports 20 MeV electron beam from an injector microtron to the booster synchrotron and Transfer line 2 transports 450 MeV electron beam from the booster synchrotron to the storage ring INDUS-I.

2. Theory

If the phase space ellipses in two transverse planes are specified at the exit of one accelerator and also at the injection point of another accelerator, then phase space matching means to find a focussing system which simultaneously transforms the two ellipses to those desired at the point of injection. One can relate the elements of the transformation matrix R to get twiss parameters at two points as, For $R = \begin{bmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{bmatrix}$ which relates x, Θ (y, ϕ) at two points.

$$\begin{bmatrix} \beta_2 \\ \alpha_2 \\ r_2 \end{bmatrix} = \begin{bmatrix} R_{11}^2 & -2R_{11}R_{12} & R_{12}^2 \\ -R_{11}R_{21} & 1+2R_{12}R_{21} & -R_{12}R_{22} \\ R_{21}^2 & -2R_{21}R_{22} & R_{22}^2 \end{bmatrix} \begin{bmatrix} \beta_1 \\ \alpha_1 \\ r_1 \end{bmatrix}$$

Thus, for two planes we have six equations, but as r is related to α and β, we have four independent equations and thus should have four variables.

To match the trajectories of off momenta particles, matching of dispersion four function η and its derivative η' is done. η and η' can be calculated using,

$$\begin{bmatrix} \eta_f \\ \eta_f' \\ 1 \end{bmatrix} = \begin{bmatrix} R_{11} & R_{12} & \eta \\ R_{21} & R_{22} & \eta' \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \eta_0 \\ \eta_0' \\ 1 \end{bmatrix}$$

η and η' in the transformation matrix have values only in the bending magnets. From the above matrix equations matching of η and η' needs two variables.

Generally the variables used to achieve these matching conditions are the strengths of the quadrupoles and lengths of the drift spaces. As the number of variables are more in transfer line, it becomes difficult to find a straight forward solution. Using computer program TRANSPORT (Brown *et al* 1980) one can find the strengths of the quadrupoles required to have desired matching conditions.

The misalignment of a magnet in a transfer line alters the beam envelope at the later point. The choice of the correcting elements is dependent on the misalignment information. For assessing the general effect of misalignments in the design stage, the change in the beam position due to uncertainties of each magnet should be known (random errors) and for provision of correcting elements, the effect of specific misalignments (systematic errors) should be known.

The apertures of the quadrupoles and the bending magnets are calculated considering the maximum beam size in the transfer line and beam excursion due to misalignments, powersupplies variations and field inaccuracies.

3. Design procedure

In Transfer line 1 phase space matching is achieved using two quadrupole doublets. To take into account the dispersion introduced by the injection septum magnet and the dispersion from the microtron, a bending magnet is introduced. Using a quadrupole doublet dispersion function η and its derivative η' are made equal to zero at the point of injection. As this reduces the septum aperture requirements and more number of turns can be injected in the same aperture. Provision for single bunch operation is made by accommodating the chopper and the slit. For analysing the microtron beam a bending magnet is provided, which will deflect the beam to the analysing section. Along the transfer line, direction of the beam

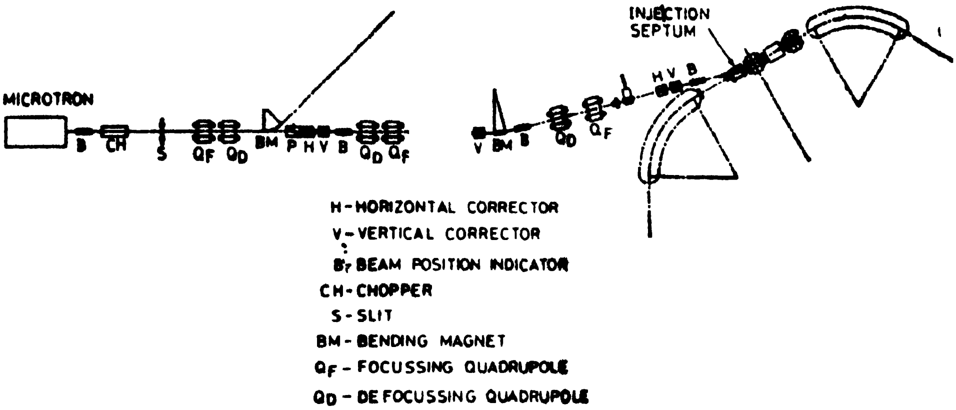

Figure 1. Layout of transfer line 1.

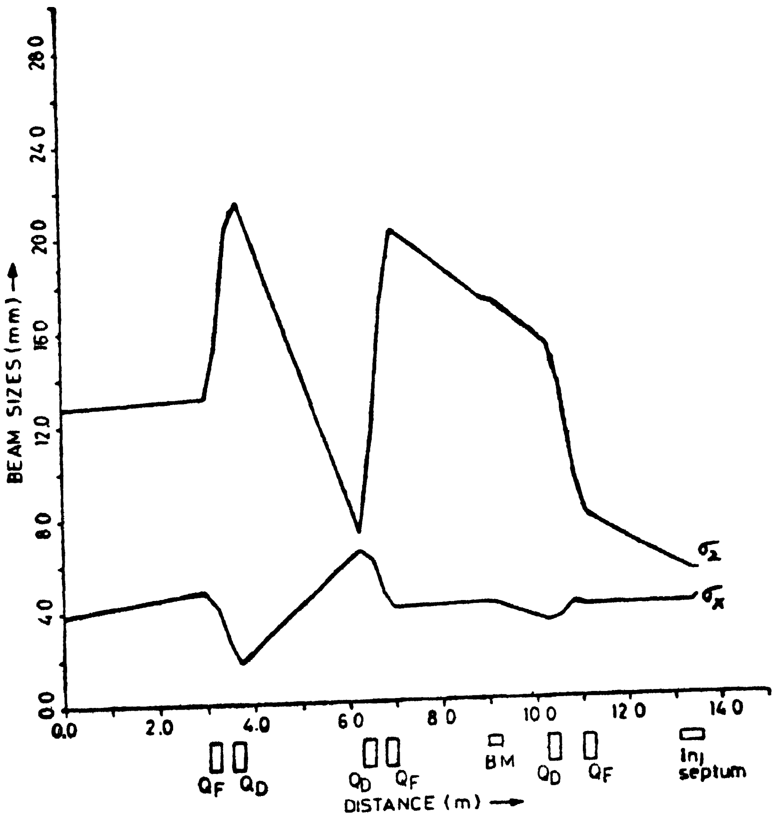

Figure 2. Beam sizes along transfer line 1. (σ_z = vertical, σ_x = horizontal).

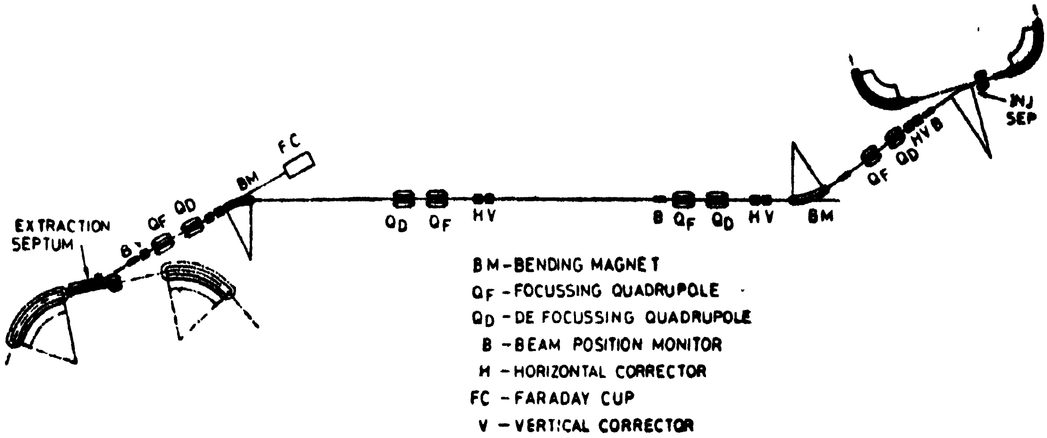

Figure 3. Layout of transfer line 2.

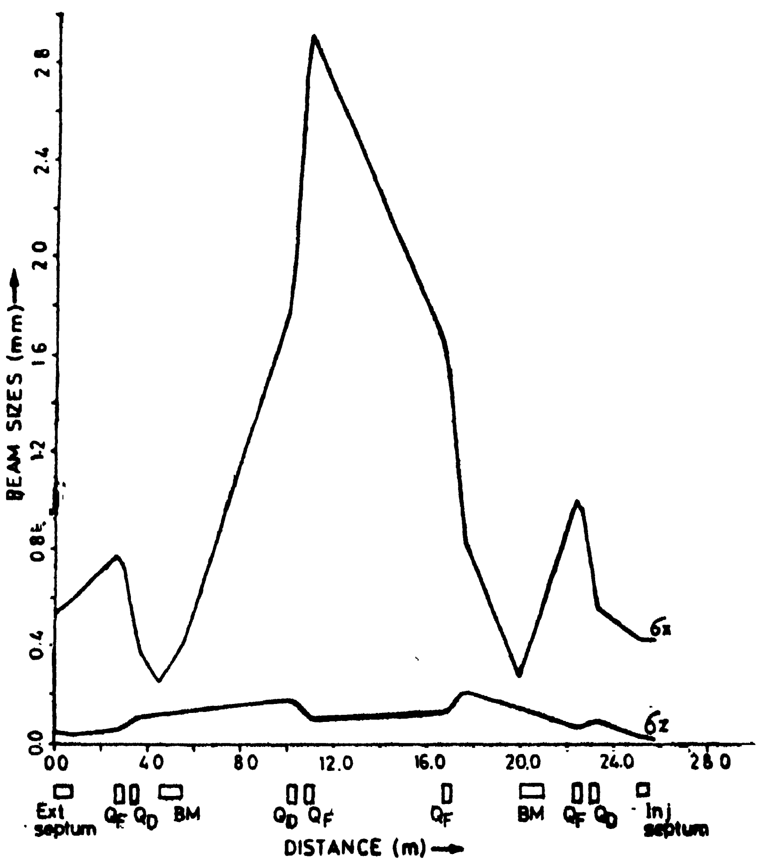

Figure 4. Beam sizes along transfer line 2 (tune 1.55, 1.56).

will be corrected using a combination of the steering magnets and beam position monitors. Other diagnostic devices such as beam profile monitors and fast current transformer are also required. The layout of Transfer line 1 is given in Figure 1. Beam sizes along the transfer line are shown in Figure 2.

In Transfer line 2 phase space matching and matching of η and η' is achieved at the storage ring injection point using four quadrupole doublets. Strengths and locations of the quadrupoles are chosen to get optimum beam sizes along the transfer line. As this transfer line is long, it is required that the trajectory should be corrected step wise. For this purpose, three pairs of steering magnets

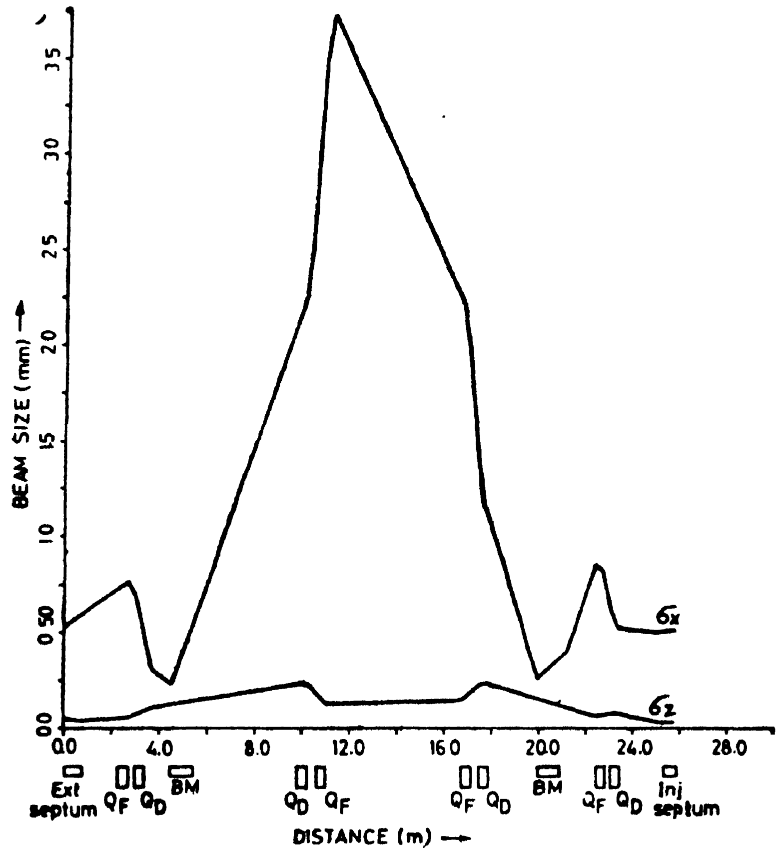

Figure 5. Beam sizes along transfer line 2 (tune 1.88, 1.22).

along with beam position monitors are located in this transfer line. Beam diagnostic devices such as beam profile monitors, fast current transformers are also required. The layout of the Transfer line 2 is given in Figure 3. Beam sizes for tunes (1.55, 1.56) and (1.88, 1.22) are shown in Figure 4 and Figure 5 respectively.

4. Results

Transfer lines 1 and 2 are designed to meet the requirements as specified in Section 2. The details of these transfer lines are specified in Table 1. The design of these Transfer lines is optimised on the basis of building layout and cost. The required lengths of the beam lines of INDUS-I are taken into consideration.

Table I. Parameters of transfer lines.

	Transfer line 1	Transfer line 2
1. Length (m)	13.5	25.8
2. Bending magnet		
Number	2	2
Length (m)	(i) 0.40	(i) 0.97738
	(ii) 0.233	(ii) 1.22173
Field (T)	(i) 0.13099	(i) 0.7505
	(ii) 0.075	(ii) 0.7505
Aperture : horz (mm)	± 30	± 20
: vert (mm)	± 20	± 15
3. Quadrupole		
Number	6	8
Length (m)	0.25	0.25
Max. Grad. (T/m)	1.5	10.0
Aperture (mm)	80	45
4. Steering magnet		
Number	5+1 on B. M.	8+2 on B. M.
Strength (mrad)	± 5	± 5
5. Beam parameters	At mic. exit	At booster exit
	$\beta_x=3.8$ m $\alpha_x=0.0$	$\beta_x=3.35$ m $\alpha_x=-0.58$
	$\beta_z=19.2$ m $\alpha_z=0.0$	$\beta_z=2.61$ m $\alpha_z=0.383$
	$\eta=0.0$ $\eta'=0.0$	$\eta=1.067$ m $\eta'=0.435$
	$\epsilon_x=3.8\ 10^{-6}$ m. rad	$\epsilon_x=8.8\ 10^{-7}$ m. rad
	$\epsilon_z=12.8\ 10^{-6}$ m. rad	$\epsilon_z=8.8\ 10^{-9}$ m. rad (10% coup)
	At booster inj pt	At storage ring inj pt
	$\beta_x=4.77$ m $\alpha_x=-0.951$	(1.88, 1.22)
	$\beta_z=2.27$ m $\alpha_z=-0.026$	$\beta_x=2.99$ m $\alpha_x=0.0$
	$\eta=1.47$ m $\eta'=0.435$	$\beta_z=0.82$ m $\alpha_z=0.0$
		$\eta=1.36$ m $\eta'=0.0$
		(1.55, 1.56)
		$\beta_x=2.02$ m $\alpha_x=0.0$
		$\beta_z=0.66$ m $\alpha_z=0.0$
		$\eta=1.66$ m $\eta'=0.0$

Reference

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